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14. ABSTRACT
We strive to improve human performance through the adaptive filtering of information. The research results will help guide the design of future crisis/battlefield management interfaces. Our experiments show: 1) eye fixations can be used as a measure of cognitive load in simple visual search tasks, 2) hand and finger pressures on a mouse indicate cognitive load in target selection tasks, 3) mouse click signatures can be used for continuous identity verification, 4) nested objects are significantly more difficult to count than adjacent objects, 5) performance decreases significantly with both map complexity and task complexity, 6) up to three static distractors make no difference in map route finding performance, 7) increasing numbers of moving distractors decreases map route finding performance, 8) having one distractor at a time move makes no difference in map route finding performance, 9) judgment of ratios is significantly easier when presented two-dimensionally rather than linearly, 10) training in one graphic data model style does not transfer to other graphic styles.

15. SUBJECT TERMS
cognitive load, information filtering, crisis management, pressure mouse, eye fixations, visual search, target selection

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FINAL PROGRESS REPORT

PROJECT TITLE: The Effectiveness of User Models in Reducing Cognitive Load

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INSTITUTION: University of Hawaii at Manoa

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OBJECTIVE:
We strive to improve human performance through the adaptive filtering of information.

APPROACH:
We conducted a series of empirical studies to determine what factors impact human performance when users extract and use information obtained from complex computer displays. In order to understand how users extract relevant information, we first needed to understand the nature of complexity in computer displays. Our initial studies showed that complexity in computer displays is a function of both the task and the individual. What may be easy for one person is hard for another and what is easy at one time for a person may be hard for the same person at another time. If we can determine the complexity of a computer display for a user at any particular time, then we can instantaneously adapt the display to optimize information throughput for this user's current capabilities. To do this, we must provide the computer with information about the state of the user. Our measurements of the user are done with an array of different physiological sensors as different sensors give different information for different tasks. Understanding how users extract information is facilitated by eye-movement studies. The type of tasks we investigated included searching for information [b2, b6, b8, p10], making decisions (information veracity and finding optimal routes) [j5, j11, b7, b8, b12, p2, p5, p8, p10, p14, p15, p16], understanding text (especially native vs. second language readers) [j3, j6, j8, j7, j9, j13, p26] and comprehending computer programs [b2, p13]. Information on the computer displays that we studied included maps (icons and routes) [b10], procedural instructions, computer programs, games [p4, p20], web sites [b1, p2, p7, p10, p14, p18, p19, p32, p38], and judgments of proportions (fractions) with different visualizations [b3, b9, p22, p31].

ACCOMPLISHMENTS (entire grant period):
We built various instrumented experimental software test-beds, including the EMI (Evaluating Multi-user Interfaces) crisis-management test-bed [b11] and the MTF (Moving Target Fractions) reconfigurable test-bed [b13, p17], which is capable of being reconfigured to handle any number of event-driven inputs (either in the test-bed or via serial ports or over TCP/IP networks) simply by editing a text file (in XML format). Even the testbed application can be easily changed. Using these test-beds, we performed experiments with human participants that found filtering of background complexity in maps during optimal route finding was helpful overall. However, we found considerable individual differences in both the users' search strategies and their perception of task complexity [j11, j12, b6, b13]. The strong individual differences inspired us to look for ways to measure these differences and to break the problem down into its components. This strategy helped us understand the complexity of the basic building blocks before recombining them into larger problems. The basic building blocks we studied included text (labels in maps), graphs (road networks), and icons.
To provide the computer information about individuals in a continuous unobtrusive manner so that the computer can adapt the presentation of information to the individual user, we designed new physiological sensors, including a Pressure Mouse (a regular computer mouse instrumented with pressure transducers on the body and buttons) and finger clips to measure galvanic skin response (GSR), blood flow and

skin/ambient temperatures and associated electronics for input of the measurements into a computer as shown in Figure 1 [b4, p4, p9, p12, p20]. Using the test-bed software, we controlled for the cognitive difficulty of tasks and found correlations in the physiological measures. We combined these biosensor measurements algorithmically in real-time into a number of "gauges" that represent different aspects of the user's state including arousal & stress, perceptual & motor load, and cognitive difficulty. These biosensors allow us to measure differences among people (e.g., the Pressure Mouse can distinguish between people in 2-3 mouse clicks) as well as differences in a single person as their cognitive state changes over time.

Figure 1. Pressure Mouse and finger/wrist sensors with A/D opto-isolation electronics.

We investigated the basic building blocks of computer displays by conducting empirical studies of text, specifically finding and judging the veracity of information, understanding procedural instructions and understanding simple computer programs [p13]. We found that even non-experts could reliably judge the veracity of domain information on the Web if the non-experts had had some instruction in general search and veracity judgment skills [p10]. For understanding procedural instructions and computer programs, we found the format (especially indenting following the logical nesting of the instructions/programs) was significant in influencing understanding. We also found that we could recognize experts versus novices simply from noting that experts fixated longer on the most salient text. We could also distinguish native versus second-language readers based on both the reader's scan patterns and the mouse usage patterns. We found added cognitive load from split attention when text and associated graphics were placed even a little bit apart. We also found that most readers had trouble comprehending graphics without meaningful labels and some readers did not even fixate on any graphics at all.
We studied the difficulty of finding and enumerating multiple arrow targets (similar to airplane depictions in radar screens) in static displays with varying difficulty of backgrounds (no distractors, obliquely oriented arrows and the more difficult oppositely oriented arrows) as shown in Figure 2 [b6]. The inspection patterns of fixations supported the idea that pre-attentive processes play a substantial role when targets are few in number, easy to locate and easy to discriminate from each other. Our results provide evidence for the operation of holistic enumeration processes that work pre-attentively at least in arrays with no distractors. When we added color to orientation of distractors using elongated ovals (similar to the depiction of ships), we found similar results. We next studied the influence of visual layout by performing empirical studies of enumerating nested versus adjacent squares and found that adjacent squares were significantly easier to process.

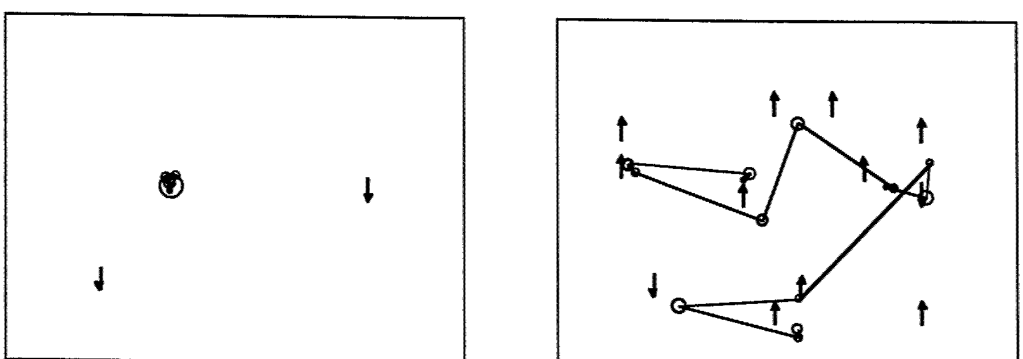

Figure 2. No distractors versus complex distractors.

We studied the perception of proportions (essential for gestalt understanding of maps) by empirical studies of proportion comparison judgments using various representations of proportions including two pairs of lines (either parallel or perpendicular pairs) or two rectangles. The rectangles were far easier to compare than perpendicular lines, which in turn were easier than parallel lines. We repeated the experiment with different shapes like ovals and circles. We found only slight differences. Very importantly, we found significant correlations between mean fixation durations in each area and complexity (both number of targets and background complexity) in all enumeration and proportion judgment tasks. This is a new, easy-to-calculate measure of cognitive load in these types of visual search tasks.
In order to test our biosensors, we wanted to add stress to the perception. Using a game of preventing the spread of an infectious disease (this was long before SARS), the user has to click (representing treatment) on a square before some time limit from the start of infection in that square to prevent the spread of disease to the neighboring squares. Over time, increasing numbers of random squares become infected. The user was given information about the progress of disease in each square by either changing color from green to red as in Figure 3, giving a changing ratio (numeric fraction), or filling in a square. We found the filling square more effective than the changing color, which was much more effective than the ratios [b3, p20].

Figure 3. Virus contamination task.

To determine whether cognitive load can be detected with our new biosensors, we designed a game where users have to click on only those fractions greater than 1/3. As shown in Figure 4, the fractions are in ovals that float in various directions across the screen. Correct selections turn green and increase the user's score while incorrect selections or missed selections (that leave the screen) turn red and decrease the user's score. Cognitive load can be controlled by changing the difficulty of fractions (e.g., 3/4 is easier to judge than 6/17) and/or by changing the rate of new fractions and/or the speed of fractions (all changeable by editing text parameters in MTF's XML file). We found correlations between the physiological measures and obvious workload measures of the task as shown in Figure 5 [b4, p4, p17].

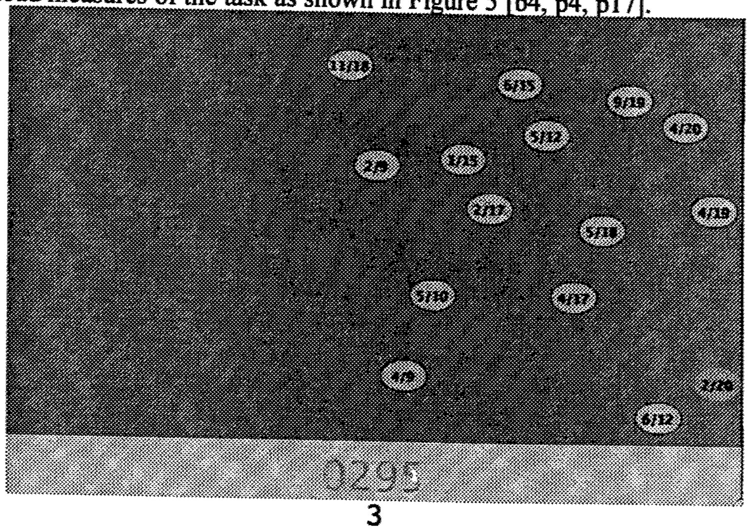

Figure 4. MTF testbed with fractions floating across the screen and the score on the bottom.

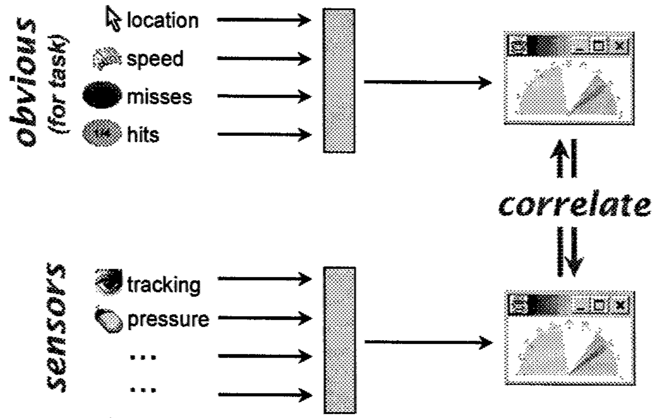

Figure 5. Correlation of biosensors with obvious task workload measures.

After detecting cognitive workload in real-time, various user interface adaptation techniques can be applied such as information filtering [b2, b4] or adapting the presentation of information to the user's cognitive load instead of or in addition to other user characteristics [j5, j6, j8, b5, b11].

SIGNIFICANCE:

The research supported by this project has produced results that will help guide the design of future crisis management and battlefield management interfaces. In particular, our completed experiments show:

1) Eye fixation durations are strongly correlated with both background complexity and number of targets in a simple visual search task. So eye fixation durations, which are very easy to calculate, can be used as a measure of cognitive load in simple visual search task and possibly in other types of tasks.
2) Hand and finger pressures on a mouse are correlated with cognitive load in target selection tasks. So hand and finger pressures on a mouse, which can be collected in a completely unintrusive manner, can be used as a measure of cognitive load in simple target selection tasks.
3) Finger pressures during a mouse click are highly individual. Within three to five clicks, identification of the individual using the mouse can be established to 90% accuracy. So click signatures can be used to help establish the identity of the user much like other biometric identification technologies. The advantage of this biometric is that it is much cheaper than other biometrics like fingerprint/handprint or retinal scanners, although it is also less accurate than these alternatives.
4) Nested objects are significantly more difficult to count than adjacent objects.
5) Performance significantly decreases with both map complexity and task complexity.
6) Up to three static distractors make no difference in map route finding performance.
7) Increasing numbers of moving distractors correlates with decreasing map route finding performance.
8) Having one distractor move at a time makes no difference in map route finding performance.
9) Judgments of ratios (represented by line length) are significantly easier when the lines are presented two-dimensionally (as rectangles) rather than linearly.
10) Training in one graphic data model style does not transfer readily to other graphic styles even for related models.

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